Integrating an ice sheet/ice shelf model into an EMIC: progress and issues

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Synopsis

- Concept
- Tools
- Coupling
- Issues
- Conclusion

Concept

- Ice sheets (i.e. WAIS/EAIS/Greenland) interact and evolve in conjunction with neighbouring components of the Earth's climate: Land, ocean, atmosphere

- A fully coupled, global climate model that includes a dynamic ice sheet/ice shelf component should:

  – capture feedbacks between ice and surrounding components

  – capture the impact of dynamic ice sheets on the global climate system

  – capture the coupled evolution of the ice/climate system
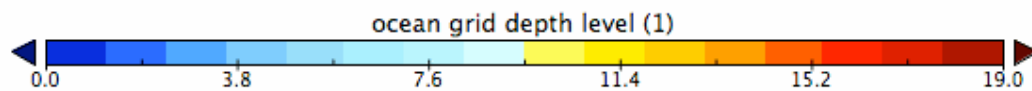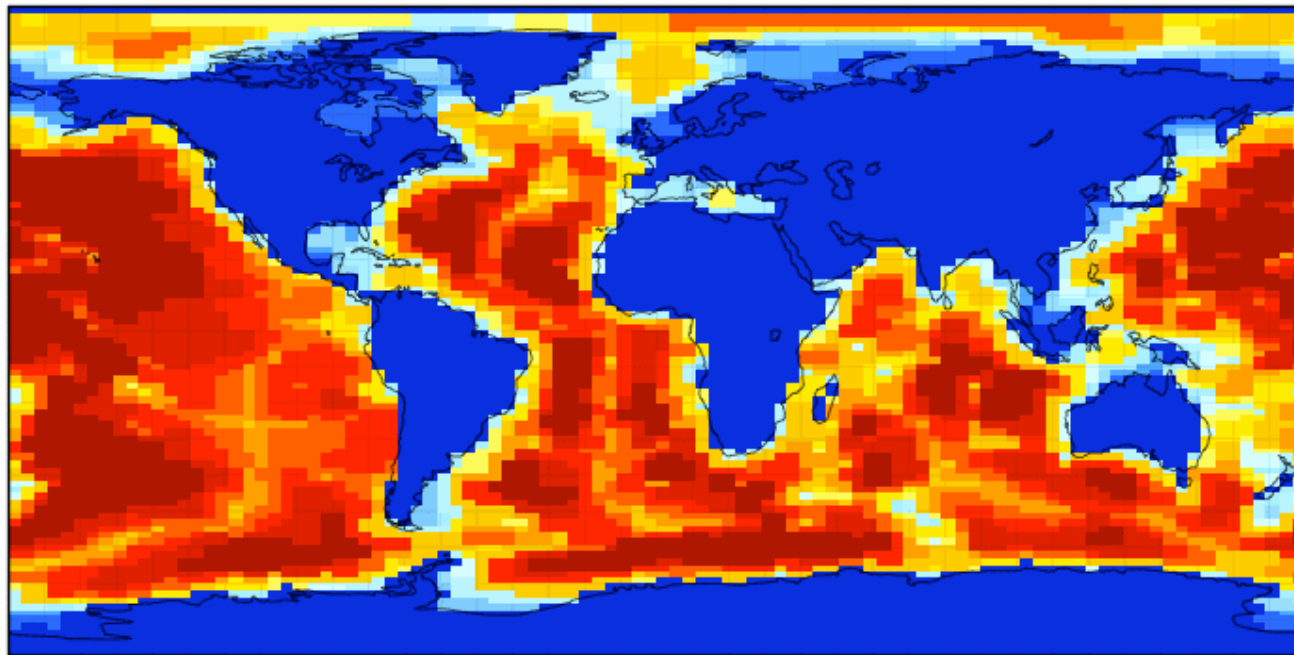
Tools being used

- Earth Model of Intermediate Complexity (EMIC): University of Victoria Earth System Climate Model

- Ice Sheet Model: David Pollard ice sheet/ice shelf model

The UVic ESCM

The Ocean

Ocean depth

ocean grid depth level (1)

0.0   3.8   7.6   11.4   15.2   19.0
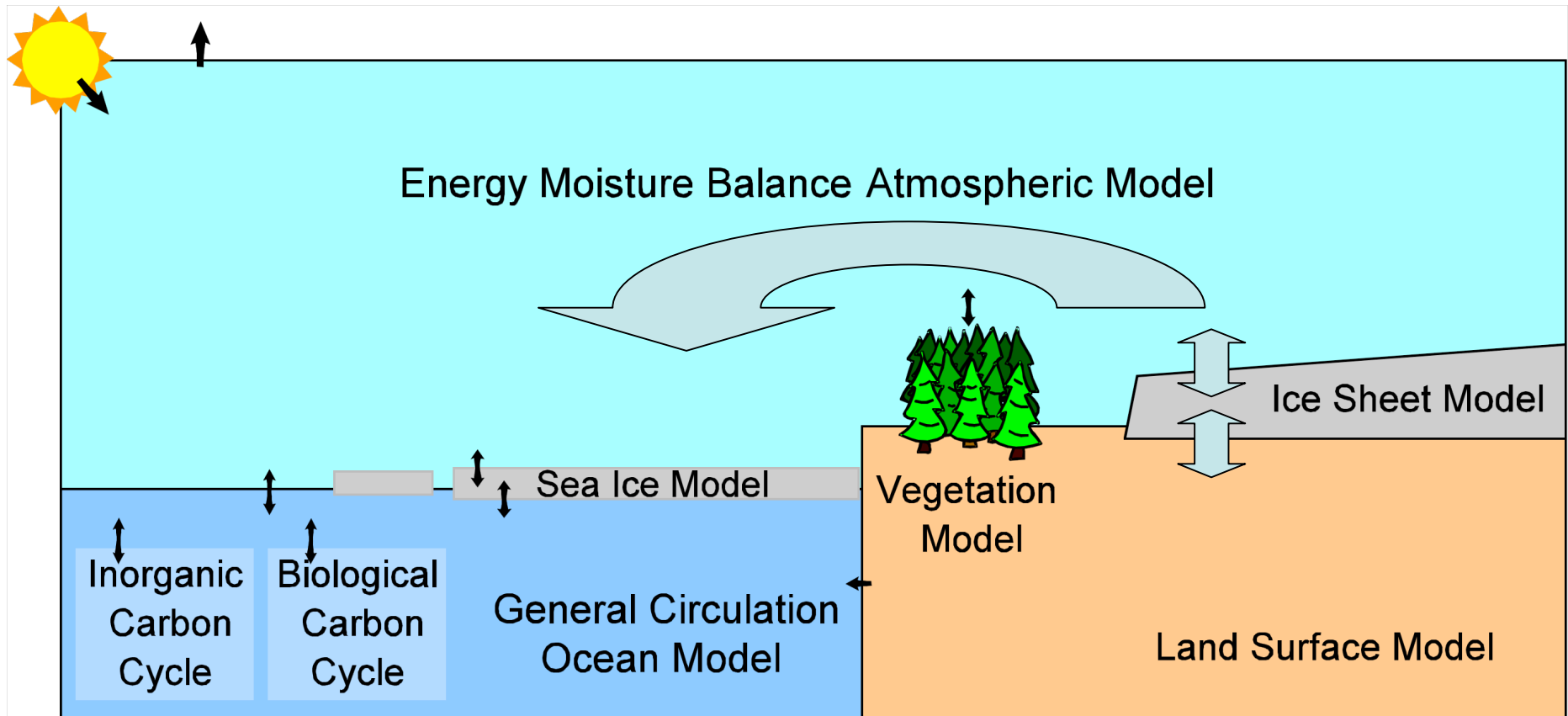
Equirectangular projection centered on 0.0°E

Data Min = 0.0, Max = 19.0

The Ocean

- 3D OGCM (MOM 2)
- 3.6° (zonal), 1.8° (meridional) resolution; 19 unequally spaced vertical levels
- 1.25 day timestep
- Non-conservative tracers: heat, freshwater
- Conservative tracers: DIC, alkalinity, oxygen isotopes, phosphate, CFCs

The Atmosphere

- Vertically integrated dynamic energy-moisture balance model
- Prescribed winds (plus a 'wind feedback option')
- Advection and diffusion of vertically integrated heat and moisture
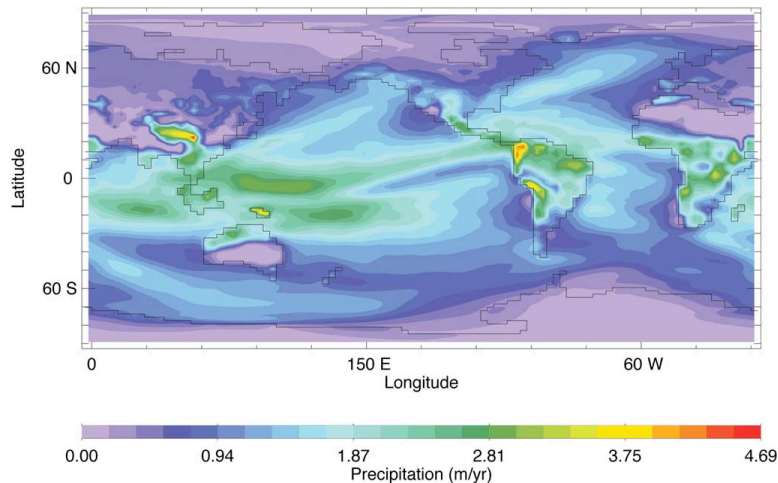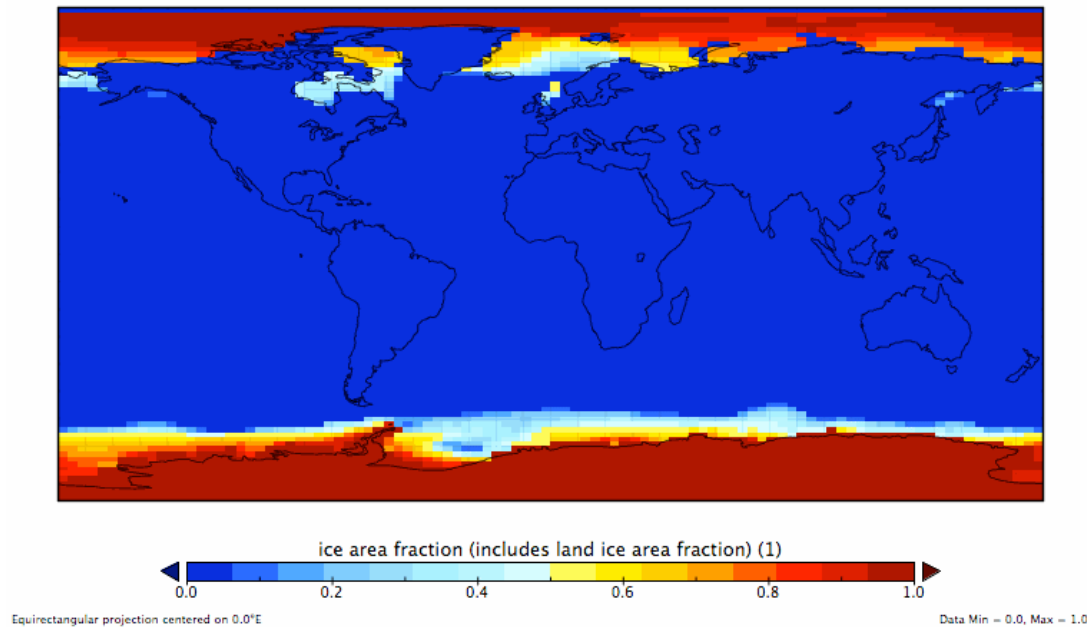

Model precipitation
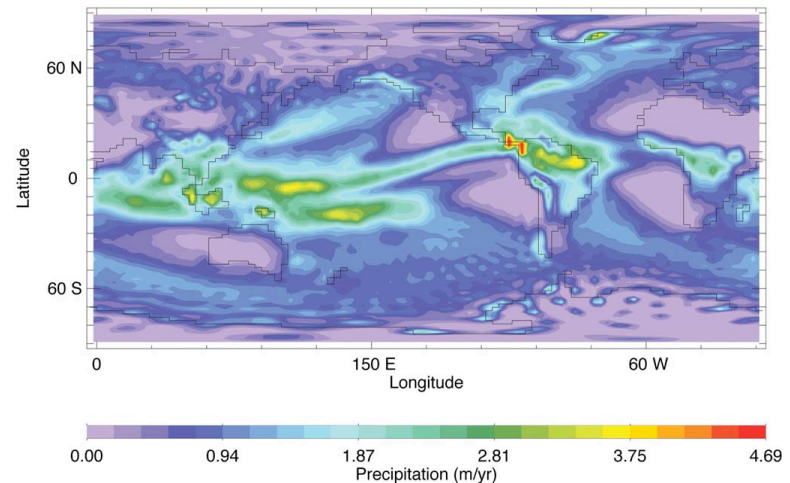

Observed precipitation

Sea Ice

- Resolves dynamics (elastic-viscous-plastic rheology) and thermodynamics of sea ice

Area of sea ice in each grid cell

ice area fraction (includes land ice area fraction) (1)

0.0   0.2   0.4   0.6   0.8   1.0

Equirectangular projection centered on 0.0°E   Data Min = 0.0, Max = 1.0

Land Surface

- Soil layer retains moisture and carbon
- 5 dynamic vegetation classes
- Datasets of human land use can be superimposed
- Runoff is instantaneous via sub-continental-scale drainage basins
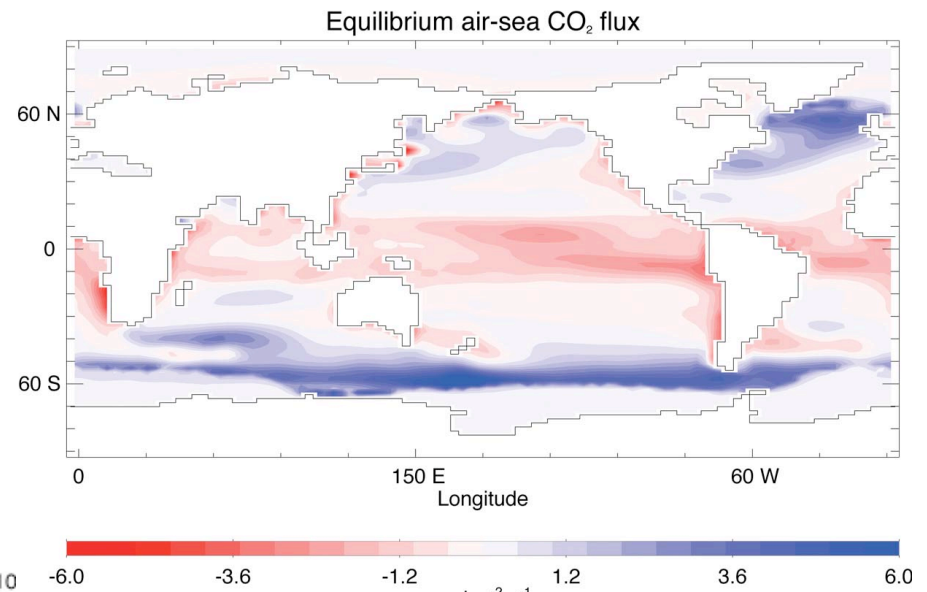

Distribution of needle leaf trees
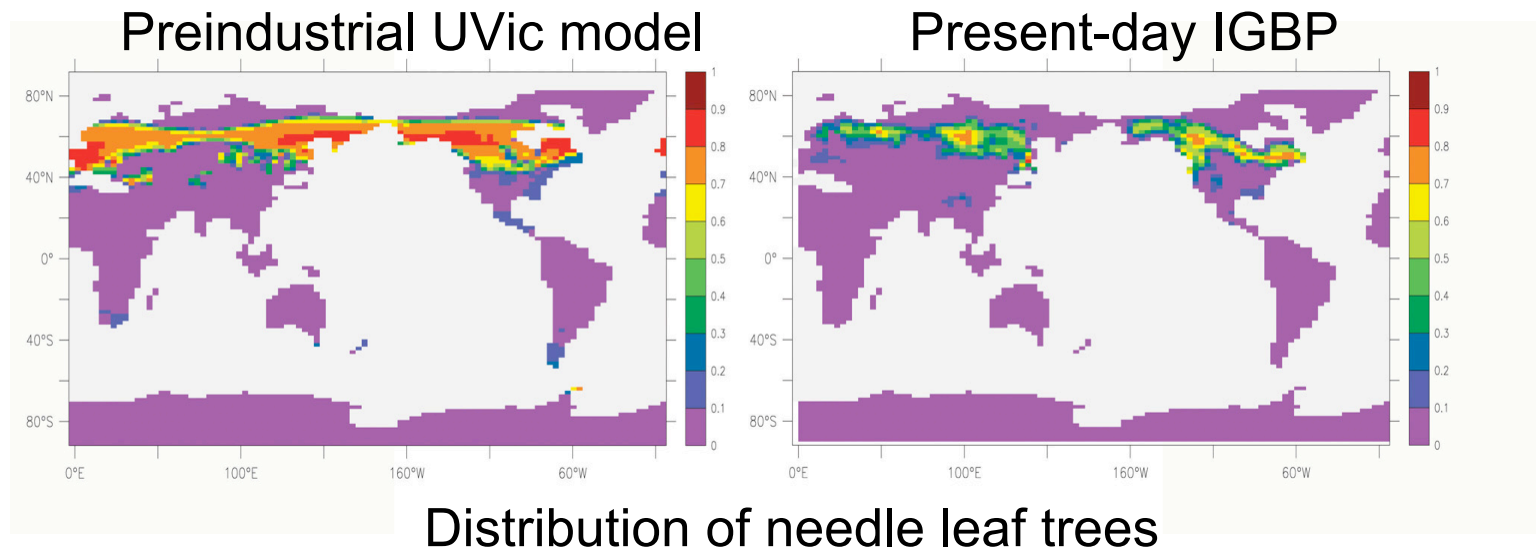
Carbon Cycle

- Carbon exchanged throughout land, ocean and atmosphere components
- Inorganic and organic carbon components
- Carbon source: human emissions
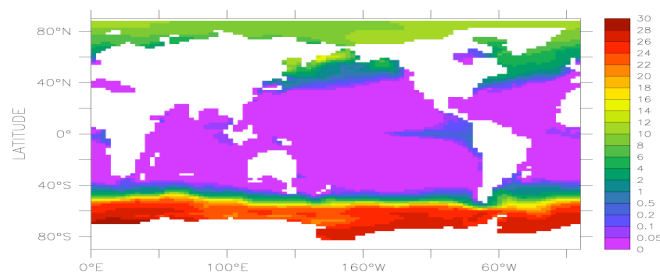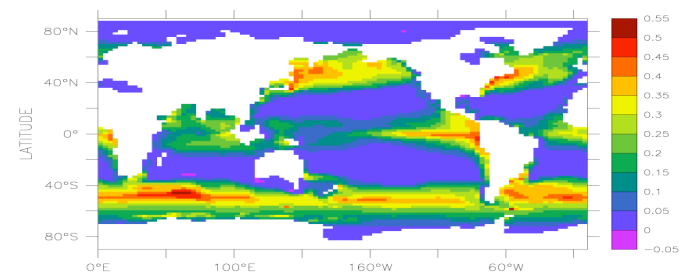- Carbon sink: seafloor carbonate burial (NEW!)
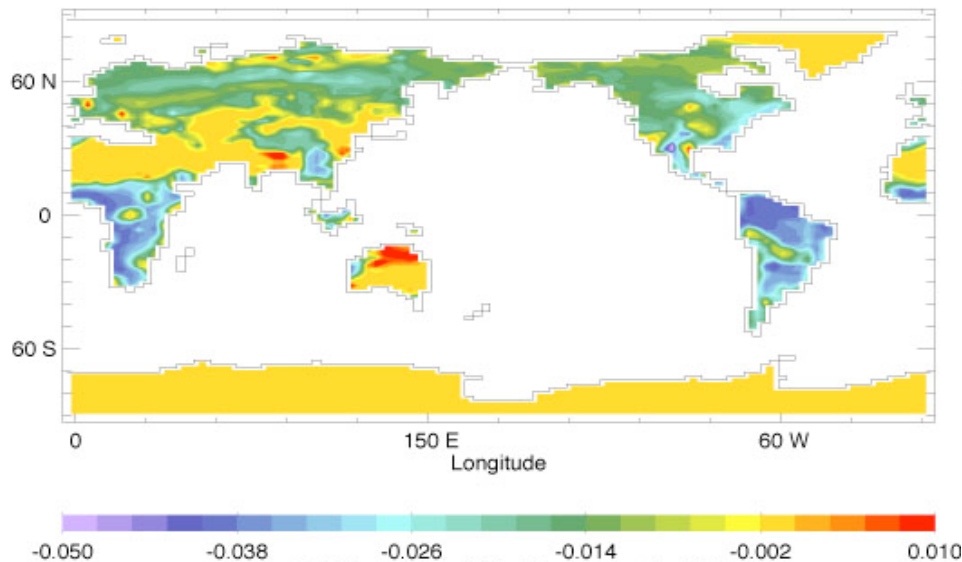
Net C flux from land

Equilibrium air-sea CO$_2$ flux
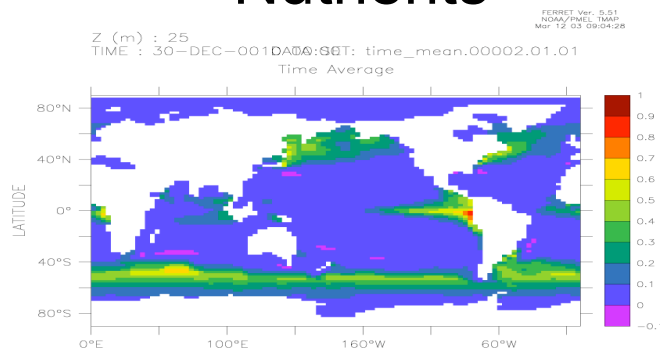
Net C flux to ocean

Ocean Biology

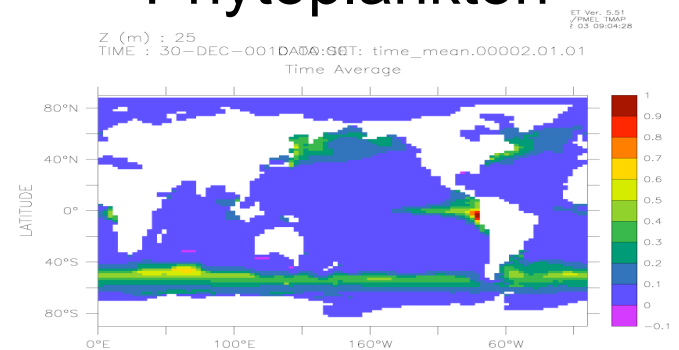• Nutrient-Phytoplankton-Zooplankton-Detritus (NZPD) model

Nutrients

Phytoplankton

Zooplankton

Detritus

The ice sheet/ice shelf model

- Combined ice sheet/ice shelf model: 'heuristically' combines shallow-ice approximation and the 'MacAyeal-style' shelf flow, depending on basal drag coefficient:

$$(U,V) = \alpha^*(u,v)_{SIA} + \beta^*(u,v)_{ISF}$$

- Imposed Schoof(2007) grounding-line velocity
- Tracer advection within ice
- Ice temperature calculation (including advection, vertical diffusion of heat, shear heating, latent heat transfer due to refreezing of precolating water in ice)
- Bedrock elevation (asthenospheric flow and elastic lithospheric flexure)

Coupling

The requirements:
- Ice sheet must run in-line as a subroutine within the climate model initialization and main loop (no conflicts between ice sheet and climate model variables)
- Must couple to all neighbouring components to exchange heat and water
- Must conserve water and heat (and any additional tracers) to machine precision, to avoid artificial gain/loss
- Must interpolate fields reasonably between ice sheet and model grids

Coupling: ice/atmosphere

- UVic ESCM uses surface energy mass balance model to generate bare ice melt/bare ice sublimation/accumulation
- Net mass balance accumulated until ice sheet timestep, then sent to ice dynamics
- SAT/SIT averaged for ice sheet thermal boundary conditions
- *On the horizon*: Subgrid elevation bins planned
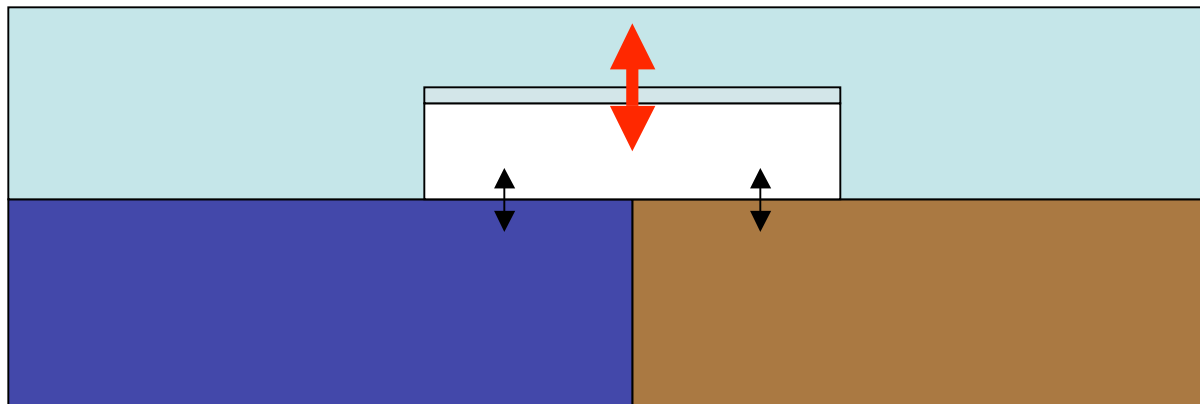
Coupling: ice/land

•Presently, ice melt/rain over ice sent directly to land bucket, which overflows instantaneously to ocean via drainage basins (no lakes).

•*On the horizon*: melt/rain percolation into ice

•*On the horizon*: subglacial hydrology in place of simple land bucket

•*On the horizon*: simultaneous existence of vegetation model and ice model in same grid cell
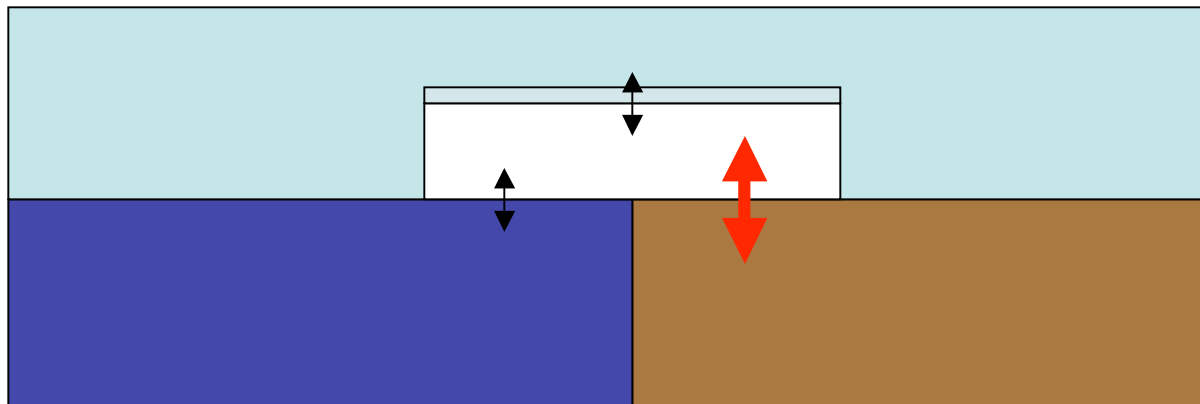
# Coupling: ice/ocean

- Ice shelf has ability to partially cover ocean cells
- Energy fluxes to sea ice are 'shaded' by ice shelf fraction (sea ice can advect under partial ice shelf cells, but will not grow or shrink)
- Initial ice sheet bathymetry/topography trimmed to avoid major coastline inconsistencies
- Currently, ice shelf surface is owned by land
- *On the horizon:* basal melt/freeze, calving
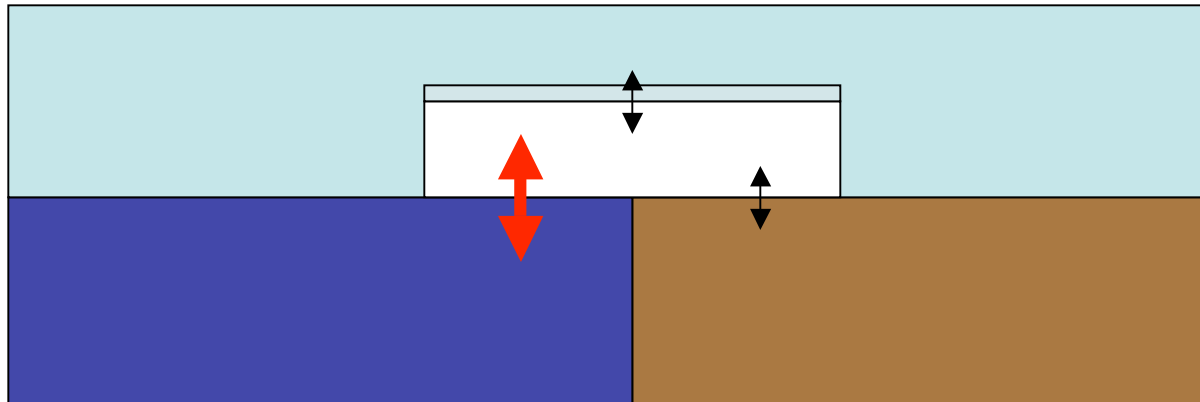
Downscaling: bilinear interpolation/nearest neighbour on lat-lon grid
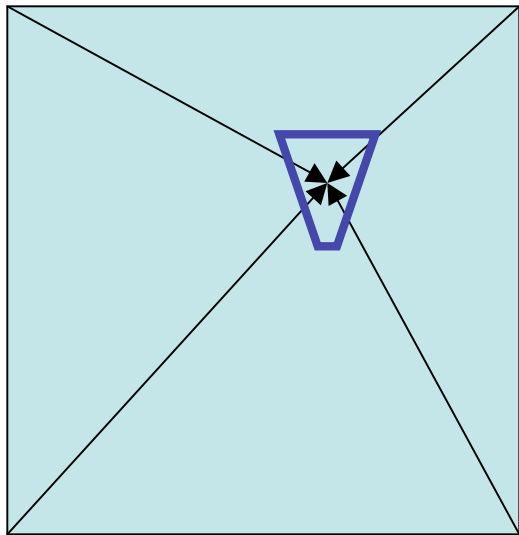
Upscaling: bilinear interpolation on subdivided polar stereographic grid, areal weighting and averaging
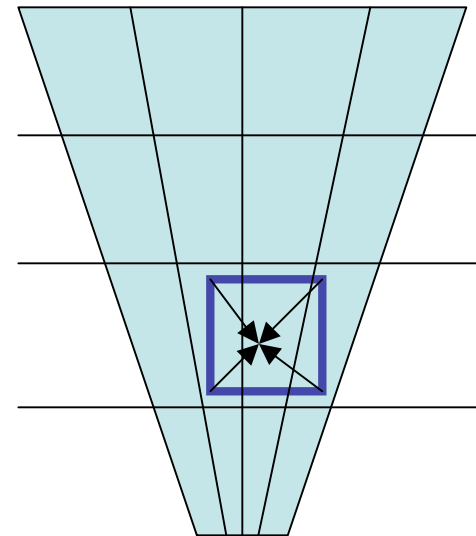
Post-interpolation correction: $\Sigma(H_{post}) = \Sigma(H_{pre})$
to obtain conservation of quantities across interpolation

Issues involved in coupling

- Problem: Exact conservation of heat and moisture
- Solution: Corrections for interpolated fields; conservation within ice sheet model

- Problem: Partial ice shelf/ocean cells
- Solution: Generalizing code to accept land, ocean and sea ice in same climate grid cell

- Problem: Dynamic grounding line
- Solution (?): initialization of a 'stagnant virtual ocean' under the ice (i.e. the West Antarctic Seaway), with imposed zero N-S/E-W gradients at edges at each timestep. As grounding line retreats/advances, MOM ocean cells 'freed up'/'frozen'

- Problem: MOM δ(bathymetry)/δt = 0.0
- Solution: ?

- Problem: Realistic representation of basal melting/freezing
- Solution (?): subgrid parameterization of melt/freeze process, regional sub-shelf model

- Problem: coarse-scale surface mass balance calculation
- Solution (?): multiple elevation bins in each grid cell

- Problem: multiple simultaneous ice sheets
- Solution: FORTRAN 95 pointer techniques (e.g. GLIMMER); allocatable arrays

Conclusions

- The ice sheet/ice shelf model of David Pollard is being coupled into the UVic Earth System Climate Model as the ice sheet component.

- The ice sheet, on an interpolated grid, must interact with land, atmosphere and ocean/sea ice model components.

- Multiple issues arise regarding the successful coupling of a dynamic ice sheet/ice shelf model into a global climate model framework. These issues are likely common to all attempts to couple ice sheets into climate models and will require alteration of climate model code (no 'plug and play'!)